Assessing The Role Of Small-Scale Bio-Optical And Bio-Acoustical Distributions In Upper Ocean Biological And Optical Processes

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LONG-TERM GOALS

Our long-term goal is to quantify the interactions between small-scale biological and physical processes within the upper ocean. This project has addressed that goal by examining specific scientific questions that relate the distribution and variability in sub-1m scale bio-optical properties with coincident spatial scales of physical properties.

OBJECTIVES

We have observed persistent thin layers (20-40cm in thickness) of biological structure in coastal environments over the past several years. These observations have raised many questions about the role of these features in upper ocean trophic dynamics, optical and acoustical signal propagation, and remote sensing. The collaborative work we have been conducting within this project is helping us to understand the mechanisms that lead to the formation and maintenance of small-scale vertical structure in the upper ocean. We address several specific objectives in order to the questions raised by these issues. We first define the small-scale structure of planktonic organisms, as identified through measurements of spectral light absorption, attenuation, light scattering, and spectral fluorescence. Those optical measurements have coincident measurements of the small-scale vertical structure in downwelling spectral irradiance, upwelling radiance, temperature, salinity, and density. We then quantify the role of physical processes such as internal waves and small-scale vertical shear in horizontal velocity on the persistence of plankton layers. These linked physical/biological measurements permit us to define the multi-dimensional parameter space in which thin layers may be found.

During 1999 we have continued our collaboration with other ONR investigators involved in the East Sound Thin Layers experiments, and we are developing interpretations of these coupled physical/biological processes. In addition, the results of these field experiments are being integrated with parallel investigations of the coastal waters over the Oregon continental shelf (see other Cowles report for N00014-97-10782).

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APPROACH

Figure 1. Free-fall profiling system with floats for buoyancy. Rosette bottles hold ~450ml.

We have approached our scientific objective through the use of vertical profiling and thermistor chain deployments, with collaborative interactions with investigators who provide ADCP-derived velocities and estimates of zooplankton abundance. We have obtained time series profiles that document the vertical patterns of bio-optical distribution and variability in several coastal oceanic habitats. We have accomplished this objective by integrating newly developed bio-optical instrumentation with a CTD into a free-fall package (Figure 1) that resolves physical, optical, and biological features over small vertical scales. We adjusted the buoyancy on the profiling package to provide 2-3 cm resolution of physical and bio-optical properties during each profile. Repeated profiles (approximately 10 per hour) provided the time series necessary to define the temporal patterns of persistence of small-scale features. During our work in East Sound in 1998, the deployment configuration consisted of a Sea-Bird 911 CTD, dual multi-wavelength absorption and attenuation meters (ac-9), a multi-wavelength spectrofluorometer which measures dissolved colored organic matter (SAFIRE), a data acquisition system (MODAPS), an Acoustic Doppler Velocimeter (ADV), and a rosette system for obtaining discrete samples during profiling. In collaboration with Dr. Sally MacIntyre, we also deployed thermistor chains just north of the sill at the entrance of East Sound and near the mooring array in the northern end of East Sound (see Holliday report and Donaghay report for more information about the mooring array).

WORK COMPLETED

In 1999 we completed analysis of nearly all of the CTD, optical, and thermistor chain data collected during the extensive collaborative field experiment in East Sound, Orcas Island, WA, during May and June 1998. These data have been distributed to co-investigators as a hard-copy data report and on a CD-ROM. The data consists of over 400 profiles of small-scale bio-optical and physical structure under a range of forcing conditions. Synthesis of our data set with data from other investigators was initiated during this funding interval. We participated in a Thin Layers Workshop in May 1999 (hosted by the Dian Gifford and Percy Donaghay, University of Rhode Island) and identified specific manuscript projects with other investigators. These collaborative syntheses are now underway.

RESULTS

Our analyses reveal several types of small-scale structure in bio-optical properties in relation to the physical structure. We documented rapid changes in the thermal structure with our moored thermistor

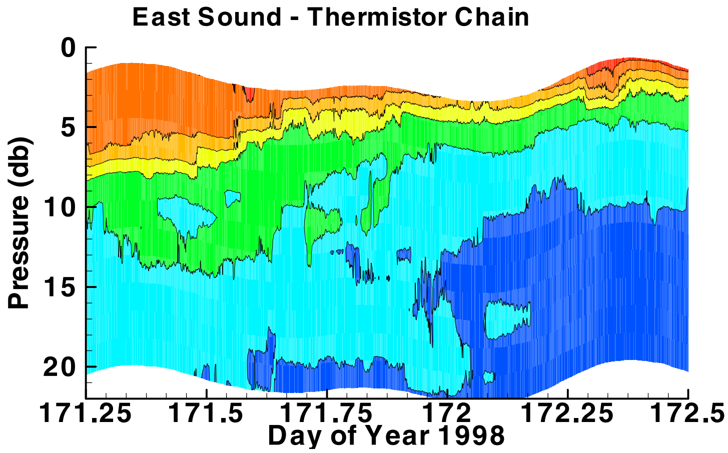

Figure 2. From 14 days of thermistor chain data, we show an example 30 hour interval (0600 June 20 – 1200 June 21). Note changes in vertical temperature structure through time created by advection.

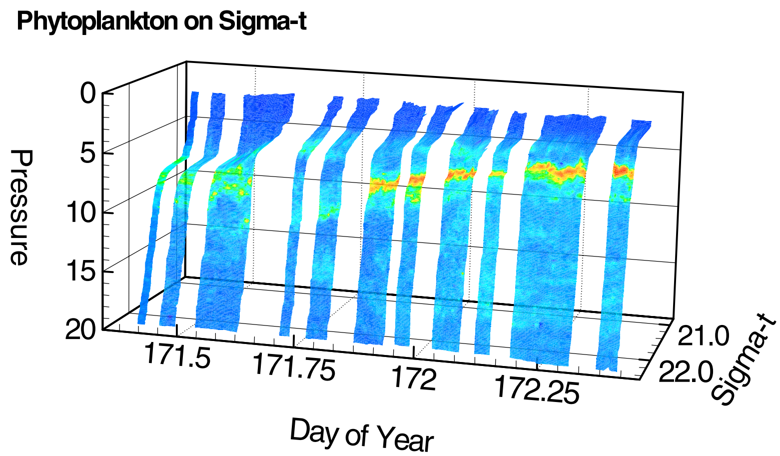

Figure 3. During the same 30 hour interval as Figure 2, a thin layer of phytoplankton (shown as color intensity) stayed within a narrow sigma-t interval and shoaled as isopycnals shoaled. This contour plot consists of over 100 profiles.

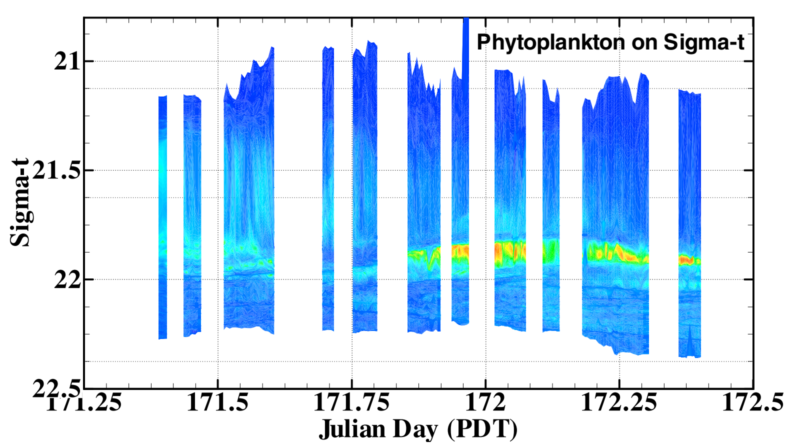

Figure 4. Phytoplankton (in color) plotted as a function of sigma-t. Note that the maximum phytoplankton concentration is centered at 21.90 during this time interval.

chain (Figure 2). During that same 30 hour interval, we observed one of many examples of a thin layer of phytoplankon that persisted for several hours (Figure 3). This thin layer, like many others observed, occupied a narrow sigma-t range over this time interval (Figure 4).

Horizontal velocity and phytoplankton structure

One fascinating result from our extensive series of profiles is the extent to which small-scale horizontal velocity is correlated to vertical density structure and vertical phytoplankton structure.

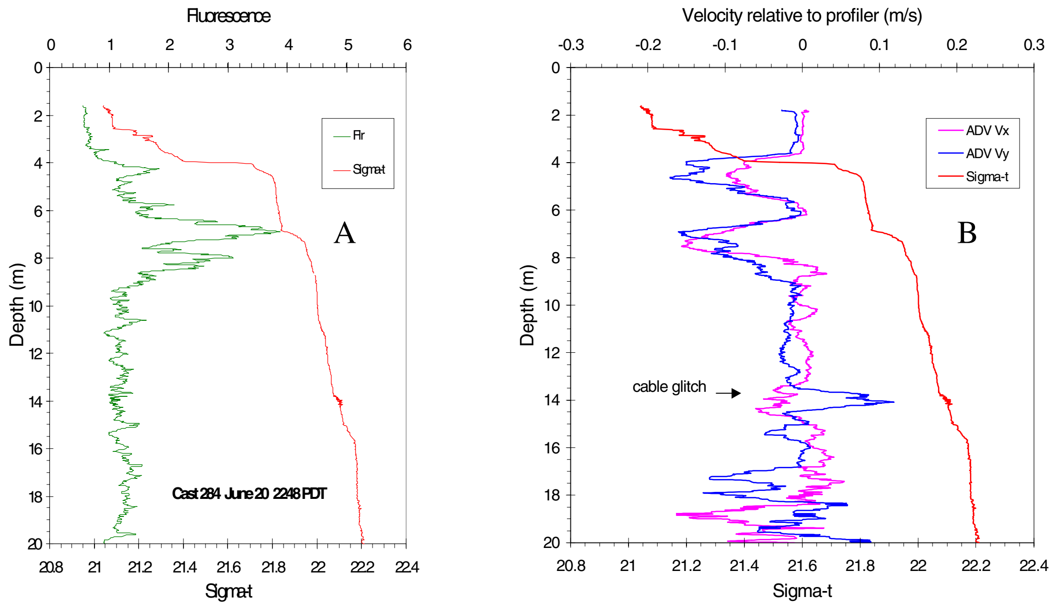

Figure 5. (A) Vertical profile of sigma-t and phytoplankton fluorescence at 2248 June 20, 1998. Note the correlation between sigma-t and the narrow bands of fluorescence at 4m and 7m. (B) Vertical profile of sigma-t and the u and v components of horizontal velocity, relative to the sinking profiler. The vertical gradient in horizontal velocity corresponds to both the sigma-t profile and the phytoplankton fluorescence profile. Note that the velocity changes reflect rotation as well as acceleration and deceleration within 1m vertical intervals.

It is clear from these results that further investigation of horizontal processes is essential for the understanding of small-scale biological structure.

IMPACT/APPLICATION

Our results suggest that additional direct assessment of the trophic implications of persistent thin layers is needed, with particular emphasis on the potential for enhanced grazing, steeper local gradients in nutrient flux and regeneration, and variations in particle flux from the euphotic zone. Our work with biological small-scale structure suggests that previous observations of small-scale biological patchiness may not have been observations of stochastic fluctuations in biological structure (i.e., patchiness), but under-sampled observations of persistent, small-scale structure. Centimeter-scale organization of planktonic biomass forces a re-evaluation of water column rate processes, and challenges our existing paradigms for sampling and experimentation over scales of meters and 10's of meters.

TRANSITIONS

The results and interpretation of the extensive data set from East Sound Thin Layers Experiment will provide new insights into the mechanisms that create that persistent pattern on small-scales. This will be essential for prediction of the impact of persistent small-scale pattern on the attenuation of optical and acoustic signals in the upper ocean. We are moving these observation techniques to oceanic study sites as we participate in the CoOP program and GLOBEC program off the coasts of northern California and Oregon during the next few years.

RELATED PROJECTS

We have active collaborations with the following ONR Principal Investigators:

Dr. Percy Donaghay, University of Rhode Island
Dr. Jan Rines, University of Rhode Island
Dr. Dian Gifford, University of Rhode Island
Dr. Alice Alldredge, UC Santa Barbara
Dr. Sally MacIntyre, UC Santa Barbara
Dr. Mary Jane Perry, University of Washington
Dr. Van Holliday, Tracor Systems
Dr. J.R. Zaneveld, Oregon State University